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THE ANALYSIS OF A CROSS FLOW HEAT EXCHANGER USED IN A SOLAR TUNNEL DRYER

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ABSTRACT

This paper presents the application of a compact size cross flow heat exchanger used in a solar tunnel dryer as an air heater. A finned type refrigerator condenser acted as a forced convection unit, which was installed between a flat plate solar collector and a drying chamber of a solar tunnel dryer have been experimentally studied. The experimental unit was constructed to test air-water fin-and-tube heat exchanger, together with a description of the numerical calculation. The first preliminary experimental results using single-phase, hot water generated from a receiver tube of a parabolic trough located on a field receiving a direct solar radiation on a sunny day. Parabolic trough focuses direct solar radiation to the receiver tube. Numerical results are presented in detail in order to both complementing the experimental information obtained, and to show its potential as an analysis and calculation. In this paper the thermal performance analysis of a cross flow unmixed heat exchanger performed by the variation of volume fraction of hot fluid, which is a hot water and air where air serves as cold fluid and water serves as a hot fluid. Cross flow heat exchanger was connected with the hot tube of the parabolic trough with a mass flow rate of hot water 0.133 kg/s. Also the volume fraction of air varied in 3 values: 0.0304, 0.0617, and 0.093 kg/s for changing the mass flow rate of air. Experimental results such as heat exchanger effectiveness, overall heat transfer coefficient, heat transfer rates have been calculated for assessing the thermal performance of the heat exchanger, mass flow rate of air and temperature of hot fluid was measured using anemometer and thermocouples respectively. These are variable depending on the inlet and outlet temperature of the fluid and effectiveness. The results indicate that, rate of heat transfer rises when the mass flow rate of air increases, but the effectiveness decline when the mass flow rate of air with increase.

KEYWORDS: Solar Tunnel Dryer, Thermal Performance, Refrigerator Condenser, Cross Flow Heat Exchanger & Thermal Performance of the Heat Exchanger

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Original Article

1. INTRODUCTION

Heat Exchangers are categorized according to their purpose and geometry. In function they are divided into three varieties as follows:

Recuperative: two fluids are separated by a solid wall, which is the most common type.

Evaporative: enthalpy of evaporation of one fluid is used to heat or cool the other fluid, for example condensers/evaporators and boilers.

Regenerative: use a third material which stores or releases heat.

There are 4 types of heat exchanger divided by their geometry: Double Tube, Shell and Tube, Cross-flow

Heat Exchangers and Compact Heat Exchangers.

Due to the limited of space cross-flow and compact heat exchangers are used. These objective to get the best out of the heat transfer surface area. Frequently used in gas (air) heating applications. The heat transfer is partial by whether the fluids are unmixed (confined in a channel) or mixed (not confined, hence free to contact several different heat transfer surfaces). Air-conditioning devices is the case of both fluids unmixed, in case of both fluids mixed include boilers. In a cross-flow heat exchanger the direction of fluids is perpendicular to each other. The required surface area, a cross for this heat exchanger is usually calculated by using tables. It is between the required surface area for counter-flow (A counter) and parallel-flow (A parallel) that is A counter< Across <A parallel.

Drying is a way of preserving food that is popular for both villagers and industries. There are many drying methods such as sun drying, hot air drying, and freeze drying. Dry by the sun will be convenient and less costly, especially solar energy is the source of heat that is obtained without cost. Traditional solar drying, such as drying fish, vegetables and fruits causes the dust problem. Microorganisms flies are carriers of pathogens and can cause worms when rain or cold. Drying may have fungal problems. As a cause for not long storage, drying with a drying cabinet from an electric power source is another method used to preserve food and preserve agricultural products. Drying products will have lower humidity causing the microorganisms in the product growing slower. The product will not decay and also has a lower weight and volume, reducing transportation costs, storage and drying with drying from this electrical power source can prevent these contaminants and when the rain falls, the product is not wet, but wastes energy and has a very high cost subsequent in high production costs. Heat exchangers are used to transfer heat between two sources hot and cold fluids. The fluid could be divided by a solid wall to avoid collaborating or it may be in direct contact [1]. Heat exchanger applications are space heating, cooling, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment. The typical example of a heat exchanger is initiated in an internal combustion engine in which a flowing fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air. Fin-and-tube heat exchangers have been engaged in industrial application such as car radiator, air conditioning, refrigeration, cryogenics, heat recovery, marine and boiler economizer, as well as many products available in the market. One of the main problems of heat exchangers is the prediction of the transient behavior which occurs during start up and shut down or during non-stationary functional. The governor of systems integrating heat exchangers is required to recognize the response of the latter to the deviations of flow rates and incoming fluid temperatures. The analysis for the response characterization and the effectiveness of heat exchanger is made for water-coolant mixture, in which the varying the quantity of coolant in the mixture, for the safe operation of heat exchangers beneath steady and transient conditions. Above the years, numerous research articles and textbooks on the design of fin-plate heat exchangers have performed in the literatures. A comprehensive periodical of solution methods for determining te effectiveness (e or P)–number of transfer units (NTU) relations for two-fluid heat exchangers with simple and complex flow arrangements is untaken by Sekulic et al. [2]. The methods were categorized by the authors as: analytical methods for obtaining exact solutions, approximate methods, curve-fit to the results from the exact solutions, numerical methods, matrix formalism, and methods based on exchanger configuration properties, as the use of flow reversal symmetry of exchanger configurations. In conformity to the authors continuing efforts to design more effective arrangements, more compact exchangers, or precise operational conditions may involve effectiveness–NTU methods for a new heat exchanger, not reported in the literature. Using roughly of these methods Pignotti and Shah [3] attained effectiveness–NTU explicit formulas for the different arrangement. The applications of compact heat exchanger in

automotive used helps in reaching great altitudes of temperature and pressure inside severe constrictions of sizes [4]. The researcher considers the importance of using solar energy to produce solar dryers to reduce environmental pollution and create dry food products. When the sun shines through the clear glass into the oven, which absorbs accumulated heat causing the temperature to be increased within the drying oven and causing the food to be heated and can be dried by solar dryer. This can greatly decrease the electrical energy consumption of a normal oven and can drain the moisture of the food in a natural way, which can transfer air inside the dryer. A number of studies have been done in last few eras for drying agricultural and food crops with a solar dryer based on the hybrid solar dryer. Reyes, Mahn, and Vásquez (2014) [5] carried out a study on the hybrid solar dryer with PCMs for dehydration of mushrooms. The temperature was maintained at up to 60 °C after recycling of air (70% to 80%). Several runs were carried out in a day and every run showed a varying darkening and shrinkage of mushrooms. Thermal efficiency swung between 22% and 62%, while the efficiency of the accumulator panel varied between 10% and 21%. The accumulator allowed to drop the electric energy input. An extensive review of different types of solar dryer based on sensible and latent heat storage is carried out. The summary of research work carried out by the different researchers on the different types of solar dryer is represented. In Paddy crop drying Jain and Jain (2004) [6] conducted a transient analytical model Indirect forced convection solar dryer and found out the thermal storage effect during the off-sunshine hour. Jain (2005) [7] studied a parametric study Indirect forced convection solar dryer Paddy crop Granite grits Thermal energy storage materials. The objective of the research were to:

- Assembly the cross flow heat exchanger with the drying chamber of solar tunnel dryer.
- Measure the hot and cold fluid temperature and mass flow rate of water. Measure air mass flow rate sent from the fan to the drying chamber.
- Calculate the experimental heat exchanger effectiveness and compare to the predicted effectiveness obtained by the NTU method.
- Study how to apply this analysis to determine cross flow heat exchanger efficiency that is suited to the solar tunnel dryer.

2. SOLAR DRYER

Solar dryers, which are used in dry foods in a better and disinfected way. The dryer has an advantage over the sun if designed properly. They make faster drying rate by making hot air up to 10-30°C [8] above the environment which makes the air moving through faster. The dryer helps to reduce moisture and prevent insects. Solar dryers that use thermal energy storage materials are quite effective for continuous drying of agricultural harvests and food products at constant temperatures (40 °C-60 °C). Become a potential replacement for the global solar energy dryer that uses fossil fuels due to the use of clean energy resources and value. Faster drying results reduce the risk of spoilage, improve product quality and yield higher results. Reduce the required drying area Solar dryers also help protect food from insect dust. Birds and animals, they can be built from materials that are relatively low in the local area. Capital costs & no fuel cost so they are useful in areas where fuel or electricity is expensive. Land of sun drying is not enough or expensive. Abundant but high humidity in the air Moreover, they may be useful in warming the air. For artificial dryers to reduce fuel cost solar food drying can be used in most areas, however. As soon as dry food is affected by many variables, especially the amount of sunlight and relative humidity. General drying time in the solar dryer is in the range of 1 to 3 days, depending on Sunlight, moving air, moisture and the type of food to be dried.

3. COMPACT HEAT EXCHANGERS

Compact heat exchangers compromise a great surface area to volume ratio naturally more than 400 m^2/m^3 for liquid-gas applications, and greater than 700 m^2/m^3 for gas-gas applications. They are often used in applications wherever space is frequently a superior such as in aircraft and automotive applications. They trust comprehensively on the use of extensive surfaces to rise the overall surface area while keeping size to a minimum. As a result, pressure drops can be high. Distinctive applications include gas-to-gas and gas-to-liquid heat exchangers. They are widely applied as oil coolers, automotive radiators, intercoolers, cryogenics, and electronics cooling applications. The overall heat transfer coefficient for this arrangement is given by:

$$\frac{1}{UA} = \frac{1}{(\eta_O hA)_i} + \frac{t}{(k_w A_w)} + \frac{1}{(\eta_O hA)_o} \tag{1}$$

Where ηo is the overall surface efficiency. In greatest compact heat exchanger design problems, the heat transfer and friction coefficients are determined from experimental performance charts or models for enhanced heat transfer surfaces [9].

The great apparent area in compact heat exchangers is accomplished by attaching thoroughly spaced thin plate or ribbed fins to the walls splitting the two fluids. Compact heat exchangers are normally used in gas-to-gas and gas-to liquid (or liquid-to-gas) heat exchangers to offset the low heat transfer coefficient related with gas flow with enlarged surface area. Car radiator, which is a water-to-air compact heat exchanger, for example, that fins are complicated in the air side of the tube surface. In compact heat exchangers, the two fluids usually move upright to each other, and such flow arrangement is called cross-flow. The cross-flow is categorized as unmixed and mixed flow, conditional on the flow pattern. In (a) the cross-flow is unmixed since the plate fins force the fluid to flow through a specific interfin spacing and avoid it from moving in the oblique direction (i.e., parallel to the tubes). The cross-flow in (b) is hypothetical to be mixed since the fluid now is free to move in the crosswise direction. Both fluids are unmixed in a car radiator. The existence of mixing in the fluid can have an important consequence on the heat transfer appearances of the heat exchanger.

4. HEAT EXCHANGER EFFECTIVENESS (NTU METHOD) [10]

If more than one of the inlet and outlet temperature of the heat exchanger is unknown, LMTD may be obtained by trial and errors solution. An additional method presents the explanation of heat exchanger effectiveness (ε), which is a dimensionless with going between 0 to1.

$$\varepsilon = \frac{q_{act}}{q_{max}} \tag{2}$$

Wherever, q_{max} is the maximum possible heat transfer for the exchanger. The maximum value could be reached if one of the fluids were to undergo a temperature change equal to the maximum temperature difference present in the exchanger, which is the difference in the incoming temperatures for the hot and cold fluids.

Let C = mCp

$$q_{act} = C_h(Th_i - Th_o) = C_c(Tc_o - Tc_i) \tag{3}$$

The maximum possible heat transfer when the fluid of small C undergoes the maximum temperature difference obtainable

$$q_{max} = C_{min}(Th_i - Tc_i) \tag{4}$$

$$q_{act} = \varepsilon C_{min}(Th_i - Tc_i) \tag{5}$$

For parallel flow H.E with combining the former three equations, we get two expressions for effectiveness

$$\varepsilon = \frac{C_h(Th_i - Th_o)}{C_{min}(Th_i - Tc_i)} = \frac{C_c(Tc_o - Tc_i)}{C_{min}(Th_i - Tc_i)} \tag{6}$$

The terms UA/Cmin is called the number of transfer units (NTU) since it is revealing of the size of the heat exchanger, i.e

$$NTU = \frac{UA}{C_{min}} \tag{7}$$

5. NUMERICAL CALCULATION

Cross flow heat exchanger calculation.

The air is heated by hot water flowing from the heat pipe of the parabolic trough to the cross flow heat exchanger which adapted from the refrigerator condenser.

Calculate the heat transfer rate:

Hypothesis

- The operation of the system is stable. Heat exchanger has a good insulation to prevent heat loss.
- Heat transfer from hot water is equal to the heat transfer to cold water.
- No changing of kinetic and potential energy.
- The overall heat transfer coefficient is stable and consistent.

Air side

The specific heat property of the air to be received is 1.005 kJ / kg℃.

Heat transfer rate analysis

$\mathring{m} = \rho AV = 1.127\ \text{kg/m}^3 \times 0.05478\ \text{m}^2 \times 1\ \text{m/s} = 0.0617\ \text{kg/s}$

$Q = [\mathring{m} \times Cp \times (T_{in} - T_{out})]$ air

Q = 0.0617 kg/s× (1.005 kJ/kg℃) × (50℃-33℃) = 1,054 W

Hot fluid on both sides has heat transfer in a cross flow heat exchanger. Good heat exchange must prevent heat loss from the environment, which is important. Allowing heat transfer from hot water is equal to the heat transfer to the cooler air. Kinetic energy changes, the potential of flowing liquid, and the overall heat transfer coefficient is constant and consistent.

The specific heat properties of the air to be received will be 1.005 kJ / kg °C.

$\Delta T_1 = T_{h,in} - T_{c,out} = 80°C – 50°C = 30°C$

$\Delta T_2 = T_{h,out} - T_{c,in} = 50°C – 33°C = 17°C$

Logarithmic mean temperatures different

$\Delta T_{lm} = \Delta T_1\text{-}\Delta T_2/(\ln(\Delta T_1/\Delta T_2)) = 30\text{-}17/(\ln(30/17)) = 22.887$ °C

Water Side

$Q = [\mathring{m} \times Cp \times (T_{in}\text{-}T_{ou}t)]water$

Q = 0.133kg/s× 4.187 kJ/kg ℃×(80-50) ℃

Q = 1.67 kW

The heat transfer surface on the outside of the pipe is determined from

$A_i = n\pi D_i L = 20 \times \pi \times 0.009 \times 0.28\ m^2 = 0.158\ m^2$

$\dot{Q} = U_i A_i F \Delta T_{lm,CF}$

$U_i = \dot{Q}/A_i F \Delta T_{lm,CF}$

F is a correction factor

$\Delta T_{lm,CF}$is a logarithm mean temperature different of a cross flow heat exchanger

$Q = U \times 0.078 \times 29.691$

$P = t_2\text{-}t_1/(T_1\text{-}t_1) = 50\text{-}80/(33\text{-}80) = 0.638$

$R = T_1\text{-}T_2/(t_2\text{-}t_1) = 33\text{-}50/(50\text{-}80) = 0.566$

Form P and R so F = 0.93

Substitute the overall heat transfer coefficient, U

$U_i = Q/(AiF\Delta T\ lm,CF) = 1{,}670\ W/(0.158 \times 0.93 \times 22.887) = 496.578\ W/m^2$ ℃

Therefore heat transfer rate,

$Q = 496.578 \times 0.078 \times 29.691 = 1{,}150.024W$

Water enters a cross flow H.E (both fluids unmixed) at 80°C and flow at the rate 0.133 kg/s to heat 0.0617 kg/s of air from 33°C. For an overall heat transfer coefficient of 496.578 W/m^2. K and an exchanger surface area of 0.158 m^2.

Determine the exit air temperature

$mcp_{air} = 0.0617 \times 1.005 = 0.0620$ kJ/s. K = 62 W/K

$mcp_{water} = 0.133 \times 4187 = 556.871$ W/K

Cmin = 0.062 ×10^{3}kJ/s. K= 62 W/K

C = Cmin/Cmax = 62/556.871 = 0.111

NTU = UA/Cmin = 496.578 × 0.158 / 62 = 1.265

$q_{act} = 1{,}150.024W$

$1,150.024W = 62\ (Th_o-33)$

$Th_o = 51.549\ °C$

$\varepsilon = q_{act}/q_{max} = 1,150.024/62(80-35) = 0.412$

6. EXPERIMENTAL SET-UP

The experiment started with the introduction of a parabolic trough, 0.8 meters wide, 1.2 meters long, exposed to the sun and connected to water pipes that passed hot water through the cross-flow heat exchanger. A compact heat exchanger, which is adapted from refrigerator condenser aluminum casing with copper tube was considered to be used as a heat exchanger. The electric fan installed in front of the heat exchanger serves to draw hot air to the drying chamber of the solar tunnel dryer as shown in Figure 1 and 2. The fan operates based on generating pressure difference and thus displacing the air from the high pressure point towards the lower pressure because of the blades movement. The maximum speed is 1,280 rpm.

Figure 1: The Cross Flow Heat Exchanger Adapted from Refrigerator Condenser was used as a Heat Exchanger in the Test.

Refrigerator condenser is a heat exchanger used to transfer thermal energy from one medium to another for the purpose of cooling. In this work while hot water is flowing downwards, water loses its heat to the air flowing pass the space between the flat tubes. The fan increases the draught of air and thereby increase the heat transfer rate. The remaining heat is absorbed by the air, which increase its temperature and hot air is sent to the drying chamber of the solar tunnel dryer.

Figure 2: The Assembly of a Cross Flow Heat Exchanger with a Drying Chamber of the Solar Tunnel Dryer.

A parabolic trough solar collector as shown in Figure 3 equipped with a tracking system made of stainless steel (SUS 304) performs as a reflector that converted solar energy into heat that focuses solar radiation to its focus which places a receiver tube. A receiver is made of copper pipe and black painted, when pass water through it, the water temperature increases and flow into a cross flow heat exchanger equipped with electric fan for generating hot wind stream to a drying chamber of the solar tunnel dryer.

Figure 3: An Adjustable Parabolic Trough with Three Thermocouples at the Center of the Pipe.

7. METHODOLOGY

The solar tunnel dryer and a parabolic trough were set up in the open area to receive full solar radiation in North-South direction on a sunny day (April 26-27, 2018). Connect the water tank to the parabolic trough by using a water hose to allow the water flow through the exposure tube. Use the same hose to connect to the other side of the parabolic trough, then connect to the heat exchanger inside the dryer. Installed a flat plate collector with the drying chamber and then turn on the water and measure the flow rate of the air (3 values: 0.0304, 0.0617, and 0.093 kg/s) and adjust the water flow rate at a constant value of 1.33 g/s. Data Logger with the accuracy of ± 10 °C was used to collect temperature data. There were 13 channels for installing K-type thermocouple cables and the solar radiation intensity according to the various positions of the system and used the hot wire anemometer to measure wind speed in the drying chamber. When finish installing various devices, switch on the measuring device to collect the temperature and solar radiation data. 22.66 kg of paddy was selected for drying material and loaded. In every 15 minutes of drying, the paddy must be weighed to determine the weight that has been reduced and then recorded the data at the same time. Measure the wind speed in the drying chamber in every 15 minutes as well. Measure wet bulb, dry bulb temperature and relative humidity.

Figure 4: Parabolic Trough Concentrated Solar Radiation to Heat Pipe and Hot Water Passed to a Cross Flow Heat Exchanger.

8. EXPERIMENTAL RESULTS

The result of numerical calculation was appreciated for valuation of the normal temperature in the solid wall separating the fluids. The fluid velocities and temperatures showed the expected overall distributions, composed of typical water and air boundary layers and of a cold water region close to the cooling air inlet section and of a warmer one close to the cooling air outlet zone. The calculated average temperature of the fluid separation wall was 324.67 K. When the water volume flow rate was 0.133 kg/s the air mass flow rate was 0.0617 kg/s, Figure 5 shows that; the heat transfer increased when the mass flow rate of air increased. In addition, that happened because when the velocity increases, the Reynolds number increases and that will increase the amount of air used to be in contact with the heat exchanger surface to reduce the heat. The maximum heat transfer is 1.9 kW at an air mass flow rate of 0.093 kg/s.

Air mass flow rate(kg/s)	Heat transfer(kW)
0.0304	0.85
0.0617	1.15
0.093	1.9

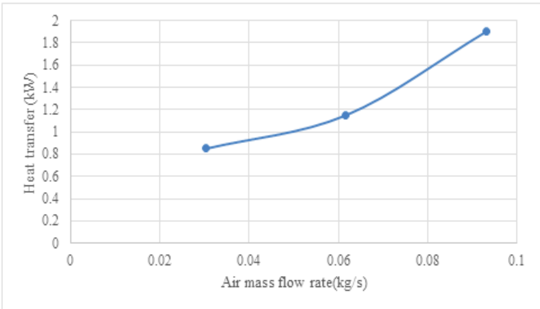

Figure 5: Heat Transfer (kW) and Air Mass Flow Rate (kg/s).

Effectiveness of the cross flow heat exchanger is the highest at 0.95 at an air mass flow rate of 0.0304 kg/s. When Air mass flow rate increases the Effectiveness would decrease.

Air mass flow rate(kg/s)	Effectiveness
0.0304	0.95
0.0617	0.94
0.093	0.92

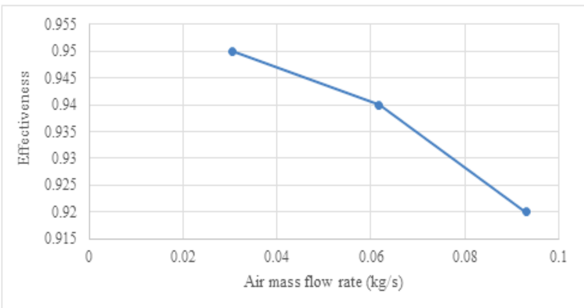

Figure 6: Effectiveness and Air Mass Flow Rate (kg/s) Relation.

Inlet water temperature entering the cross flow heat exchanger varied due to the increase in solar intensity. The more solar intensity, the higher water temperature gained. The maximum solar Intensity in this experiment was nearly 900

W/m²made the inlet water temperature closed in 80 °C illustrated in Figure 7. The outlet air temperature from the cross flow heat exchanger was 50°C entering to the drying chamber, which was suitable for drying product.

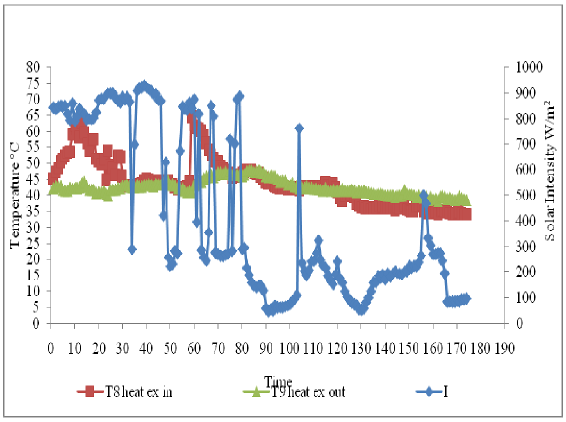

Figure 7: Temperature of the Cross Flow Heat Exchanger and Solar Intensity vs Time.

9. CONCLUSIONS

In this work an air–water compact heat exchanger, aluminum alloy made modified from refrigerator condenser, was experimentally and numerically investigated. Thermal characteristics of a cross flow heat exchanger such as the overall heat transfer coefficient, rate of heat transfer, NTU and the effectiveness were calculated as well as Th_o of exit air to the drying chamber for comparison with experimental data and for performance prediction in the nominal operation conditions. The outlet air temperature (50°C) appeared to be consistent with the calculation of the heat exchanger (51.549°C). According to the study, the total rate of heat transfer, heat transfer coefficient and area depends on the mass flow rate of the air, and the direction of air and water flow from the direction of the flow of air and flowing water in the opposite direction, the performance is higher than the parallel flow. When comparing the prices of modified heat exchangers with cross-flow heat exchanger equipment that uses a serrated spiral-type fin pipe have a much lower price. Even though the received heat transfer performance is slightly higher, therefore, the adapted condenser is possible to use practically for a solar tunnel dryer as an air heater. The results indicate that, rate of heat transfer rises when the mass flow rate of air increases, but the effectiveness decline when the mass flow rate of air with increase.

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